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Electrolyte Gating of Correlated Electron Materials and Nanostructures in Complex Oxides

David Goldhaber-Gordon
LELAND STANFORD JUNIOR UNIV CA

09/17/2015
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB1
Arlington, Virginia 22203
Air Force Materiel Command

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Limits of conventional transistor operation are set by the material parameters of Silicon (Si), the most common semiconductor material used today. Moving to other materials with higher mobility (carbon nanotubes, III-V semiconductors) no longer looks like it will have much impact, as Si mobility has been improved by strain engineering, and devices have gotten so small that mobility is no longer a limiting factor. But can we gain in performance and functionality by making a more dramatic change: using a fundamentally different switching principle? We propose to investigate the basic physics behind the Mott transition with an eye toward creating novel nanoscale and superconducting devices. Specifically, we plan to study materials where interactions and spin physics play a role (notably spin liquids) and materials in which local conduction has recently been achieved or discovered (conducting lines in oxide heterostructures written by conductive AFM (cAFM), and conducting paths at ferroelectric domain walls in oxide heterostructures). In all these cases, we will tune conduction using electrolyte gating.

15. SUBJECT TERMS
Electrolyte gating, complex oxides, strongly-correlated electrons, Mott transition, spin liquids

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Final Report Submitted to the

Air Force Office of Scientific Research

for research on

Electrolyte Gating of Correlated Electron Materials and Nanostructures in Complex Oxides

Contract # FA9550-12-1-0252

Principal Investigator:

D. Goldhaber-Gordon

Geballe Laboratory for Advanced Materials
McCullough Building Room 346
476 Lomita Mall
Stanford University
Stanford, CA 94305

September, 2015

Objectives:

Power consumption has become a major obstacle to the continuation of Moore's law. In addition, the proliferation of mobile electronics demands the creation of devices that can run for longer off a given battery. Specific to the Air Force mission, lower-power, smaller, lighter devices will allow for longer-lasting unmanned aerial vehicle missions. Developing a transistor that can switch more abruptly from “on” to “off” could enable operation with lower gate voltages and hence lower power. One promising approach toward this idea is to use materials in which electrons organize collectively rather than behave like independent particles. We aimed to use this philosophy together with novel techniques of gating materials with very large carrier density.

Status of effort:

From the beginning to the end of funding, May 15, 2012 to May 14, 2015, was three years, but funding was interrupted for about 6 months during this period due to budgetary uncertainty at AFOSR. Hence some work was held up, and some needed to be pursued jointly with an ARO program. We nonetheless demonstrated some key accomplishments as described below, which advance toward the ultimate objectives of this program.

Accomplishments:

1. Electrolyte gating has become a popular approach to accumulating large carrier densities at the surface of materials, and thus transforming electronic properties of those materials. However, the lateral lengthscale of carrier accumulation was always large (tens of microns to millimeters). We demonstrated that accumulation could be patterned down to 100 nanometers, and used that to ability to create an electrically tunable Josephson junction.

2. We demonstrated that electrolyte gating can work even through a dielectric, and that (remarkably) the carrier density that can be accumulated remains several times higher than the maximum achievable with conventional gating. The mobility of surface carriers is over an order of magnitude higher than without the intervening dielectric, and the dielectric blocks chemical reactions between electrolyte and substrate, opening the possibility to apply this technique to a wide variety of materials.

Personnel supported or associated with work:

Principal Investigator:

David Goldhaber-Gordon, Professor of Physics

Graduate students:

Patrick Gallagher, Ph.D. student in Physics. Graduation expected August 2016. Worked on electrolyte gating of complex oxides on nanometer scales and through Boron Nitride. (AFOSR supplemented Stanford and external fellowships)

Sam Stanwyck, Ph.D. student in Applied Physics: Worked on electrolyte gating of multiple complex oxides, and SrTiO3 on nanometer scales. Graduation expected June 2017.

Publications or notable interactions:

- Patrick Gallagher, Menyoung Lee, Trevor A. Petach, Sam W. Stanwyck, James R. Williams, Kenji Watanabe, Takashi Taniguchi, David Goldhaber-Gordon, "A high-mobility electronic system at an electrolyte-gated oxide surface," Nature Communications 6, 6437 (2015).
- Patrick Gallagher, Menyoung Lee, James R. Williams, David Goldhaber-Gordon, "Gate-tunable superconducting weak link and quantum point contact spectroscopy on a strontium titanate surface" Nature Physics 10, 748 (2014).
- Sam W. Stanwyck, P. Gallagher, J. R. Williams and David Goldhaber-Gordon, "Universal conductance fluctuations in electrolyte-gated SrTiO3 nanostructures" Applied Physics Letters 103, 213504 (2013). The acknowledgments somehow seem to have been stripped out, but this was supported on the grant reported on here.

New discoveries since latest progress report:

Demonstration of electrolyte gating through ~ 1 nm boron nitride.

Honors/Awards:

2002 AFOSR Presidential Early Career Award in Science and Engineering (PECASE) (*actually awarded 2004*). Awarded to two early-career scientists or engineers per year.

2004 David and Lucille Packard Fellow. 16 awarded nationwide to early-career faculty across all fields of science and engineering.

2006 National Academy of Sciences Award for Initiatives in Research

2010 Weston Visiting Professor, Weizmann Institute

2013 Promoted to Full Professor of Physics at Stanford

1.

1. Report Type

Final Report

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goldhabergordon@gmail.com

Primary Contact Phone Number

Contact phone number if there is a problem with the report

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Stanford University

Grant/Contract Title

The full title of the funded effort.

Electrolyte Gating of Correlated Electron Materials and Nanostructures in Complex Oxides

Grant/Contract Number

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0252

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

DAVID GOLDHABER

Program Manager

The AFOSR Program Manager currently assigned to the award

Harold Weinstock

Reporting Period Start Date

05/15/2012

Reporting Period End Date

05/14/2015

Abstract

1. Electrolyte gating has become a popular approach to accumulating large carrier densities at the surface of materials, and thus transforming electronic properties of those materials. However, the lateral lengthscale of carrier accumulation was always large (tens of microns to millimeters). We demonstrated that accumulation could be patterned down to 100 nanometers, and used that to ability to create an electrically tunable Josephson junction.

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Archival Publications (published) during reporting period:

• Patrick Gallagher, Menyoung Lee, Trevor A. Petach, Sam W. Stanwyck, James R. Williams, Kenji Watanabe, Takashi Taniguchi, David Goldhaber-Gordon, "A high-mobility electronic system at an electrolyte-gated oxide surface," Nature Communications 6, 6437 (2015).
• Patrick Gallagher, Menyoung Lee, James R. Williams, David Goldhaber-Gordon, "Gate-tunable superconducting weak link and quantum point contact spectroscopy on a strontium titanate surface" Nature Physics 10, 748 (2014).
• Sam W. Stanwyck, P. Gallagher, J. R. Williams and David Goldhaber-Gordon, "Universal conductance fluctuations in electrolyte-gated $SrTiO_3$ nanostructures" Applied Physics Letters 103, 213504 (2013). The acknowledgments somehow seem to have been stripped out, but this was supported on the grant reported on here.

Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

My final report is several weeks late.

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

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Appendix Documents

2. Thank You

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